View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Elsevier - Publisher Connector

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Nuclear Physics B (Proc. Suppl.) 234 (2013) 165–168

NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS

www.elsevier.com/locate/npbps

Studies of Hadronic B Decays at LHCb☆

F. Zhang*,a,b

[a] Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education, Tsinghua University, Beijing 100084, China
[b] Department of Engineering Physics, Tsinghua University, Beijing 100084, China

Abstract

Hadronic B decays are important decays for CP-violation studies and to search for beyond the Standard Model (SM) effects. CP-violation results obtained from the decays $B \to DK$ where D represents D^0 or $\bar{D}^0$ and from the decays $B \to hh$ where h denotes K or π are presented. The $B \to DK$ decay modes are due to tree level diagrams while the $B \to hh$ are sensitive to loop diagrams and thus to New Physics. Results from a full angular analysis of the $B_s^0 \to \phi\phi$ decay modes are also presented as well as the effective lifetime measurement using the $B_s^0 \to KK$ mode. The analyses presented here are based on 1.0 fb^{-1} pp collision data collected in 2011 with the LHCb detector.

1. Introduction

The LHCb detector[1] is a single arm spectrometer for precise measurements of B and D meson decays at Large Hadron Collider (LHC). The hadronic B decays offer opportunities for CP-violation measurements and validation of the SM.

The $B \to DK$ decay mode is purely due to tree level diagrams and thus is expected to be free from New Physics contributions[2]. It is extremely clean with an irreducible uncertainty of $\delta\gamma/\gamma \sim 10^{-6}$ and allows for a benchmark measurement of the CKM phase γ to check the CKM matrix paradigm.

Measurements of CP-violation and branching fractions in $B^0 \to h^\pm h^\mp$ decays provide a complementary way to extract γ[2]. However, the decay amplitudes receive contributions not only from tree diagrams, but also from penguin diagrams, which are sensitive to the possible presence of New Physics.

In the SM the $B_s^0 \to \phi\phi$ decay is a flavor-changing-neutral-current (FCNC) process via a $b \to s\bar{s}s$ penguin transition. Studies of the polarization amplitudes and triple product asymmetries can provide powerful tests of the SM and the presence of contributions of New Physics[3, 4, 5].

Measurement of the effective $B_s^0 \to K^+K^-$ lifetime can be used to constrain contributions from physics beyond the SM in the B_s^0 meson system[6, 7, 8, 9].

The results presented in this talk are (partly) based on 1.0 fb^{-1} pp collision data collected by the LHCb detector at a center of mass energy of $\sqrt{s} = 7$ TeV in 2011.

2. $B \to DK$

The Cabibbo favored process $B \to \bar{D}^0 K$ and the suppressed process $B \to D^0 K$ can be described with three parameters: the weak phase difference γ, a strong phase difference δ_B and the ratio of magnitudes between the favored and suppressed amplitudes, denoted r_B. If the D^0 and $\bar{D}^0$ decay to a common final state, then the interference between the two amplitudes allows γ to be determined.

The Gronau-London-Wyler (GLW) strategy[10, 11] exploits CP decays of the D^0 meson : $D^0 \to KK$ and $D^0 \to \pi\pi$. No additional unknown is added to the three parameters. The method has been extended to non CP-eigenstates $K^-\pi^+$ (Cabibbo Favored, CF), $K^+\pi^-$ (Double Cabibbo Suppressed, (DCS)) decay modes by so called Atwood-Duinetz-Soni (ADS) strategy[12, 13]. In this case, two unknown parameters are added: the ratio of branching fractions of D^0 decays into state f respect to $\bar{D}^0$ decays into $\bar{f}$ and a difference of strong phase. However constraints are provided by the CLEO-c experiment.

The results of the GLW analysis are shown in Figures 1 and 2 based on 1.0 fb^{-1} data. An asymmetry is clearly visible for the DK modes and the combined CP-violation significance is 4.5σ. No CP asymmetry is visible for the $B \to D\pi$ modes due to the very small value of the $b \to u$ to $b \to c$ amplitudes ratio.

☆On Behalf of the LHCb Collaboration.

*Corresponding author
Email address: f.zhang@cern.ch (F. Zhang)

© CERN for the benefit of the LHCb Collaboration.

0920-5632/ © 2013 CERN Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.nuclphysbps.2012.12.006

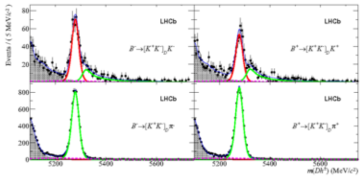

Figure 1: Invariant mass distributions of selected $B^\pm \to [K^+K^-]_D h^\pm$ candidates. The left plots are B^- candidates, B^+ are on the right.[14]

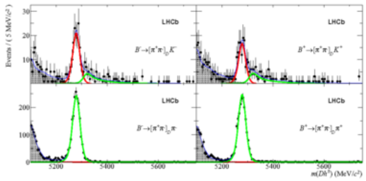

Figure 2: Invariant mass distributions of selected $B^\pm \to [\pi^+\pi^-]_D h^\pm$ candidates.[14]

The results of the ADS analysis are shown in Figures 3 and 4. The LHCb experiment shows the first observation of the DCS mode $B \to [\pi K]_D K$. The $B^\pm \to DK^\pm$ ADS mode displays evidence (4.0 σ) of a large negative asymmetry. The $B^\pm \to D\pi^\pm$ ADS mode shows a hint of a positive asymmetry with 2.4σ significance.

The general quantities $R_{CP+}, A_{CP+}, R_{ADS}, A_{ADS}$ are deduced by simultaneously fitting the invariant mass distributions of B candidates. LHCb gives the world best measurements of those observables to be [15]

$$R_{CP+} = 1.007 \pm 0.038 \pm 0.012 \tag{1}$$

$$A_{CP+} = 0.145 \pm 0.032 \pm 0.010 \tag{2}$$

$$R_{ADS} = 0.0152 \pm 0.0020 \pm 0.0004 \tag{3}$$

$$A_{ADS} = -0.52 \pm 0.15 \pm 0.02 \tag{4}$$

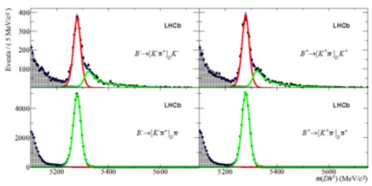

Figure 3: Invariant mass distributions of selected $B^\pm \to [K^\pm\pi^\mp]_D h^\pm$ candidates. [14]

3. $B \to hh$

As already said, $B \to hh$ decays provide a complementary way to extract γ. Here B denotes either a B^0 or

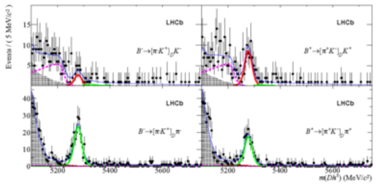

Figure 4: Invariant mass distributions of selected $B^\pm \to [K^\mp\pi^\pm]_D h^\pm$ candidates. [14]

B_s^0 and h either a K or a π. There are six decays in total. However, unlike the $B \to DK$, those decays have contributions from Tree(T), Penguin(P), Penguin Annihilation(PA), Color-suppressed Electroweak Penguin(P_{EW}^C) and Exchange topologies(E) Feynman diagrams [2].

Generally, γ is determined from the CP-violating asymmetries in $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ decays within the validity of the U-spin symmetry which relates the amplitudes of these two decays. The time dependent CP asymmetries in these two decays can be written as

$$\begin{aligned} A(t) &= \frac{\Gamma(t)(\bar{B}^0_{(S)} \to h^+h^-) - \Gamma(t)(B^0_{(S)} \to h^+h^-)}{\Gamma(t)(\bar{B}^0_{(S)} \to h^+h^-) + \Gamma(t)(B^0_{(S)} \to h^+h^-)} \\ &= \frac{A^{\mathrm{dir}}\cos(\Delta m t) + A^{\mathrm{mix}}\sin(\Delta m t)}{\cosh(\frac{\Delta\Gamma}{2}t) - A^{\Delta\Gamma}\sinh(\frac{\Delta\Gamma}{2}t)} \end{aligned} \tag{5}$$

where A^{dir} denotes direct CP-violation and A^{mix} denotes CP-violation introduced by the interference between decay and mixing.

Using an integrated luminosity of 0.69 fb^{-1} data collected in 2011, the time dependent raw asymmetries in $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ are shown in Figures 5 and 6 respectively [16].

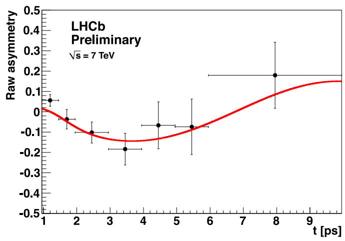

Figure 5: Time dependent raw asymmetry in $B^0 \to \pi^+\pi^-$ decay [16]

The validity of the U-spin symmetry assumption can be probed by comparing $A_{\pi\pi}^{\mathrm{dir}}$ and the direct CP asymmetry in the $B_s^0 \to \pi^+K^-$ decay or A_{KK}^{dir} and the direct CP asymmetry in the $B^0 \to K^+\pi^-$ decay. The sizes of PA and E contributions can be probed by measuring the

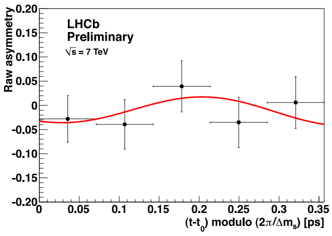

Figure 6: Time dependent raw asymmetry in $B_s^0 \to K^+K^-$ decay [16]

branching ratios of $B^0 \to K^+K^-$ and $B_s^0 \to \pi^+\pi^-$ which are only sensitive to these two topologies.

The analysis of LHCb gives preliminary result for $A_{\pi\pi}^{\rm dir} = 0.11 \pm 0.21 \pm 0.03$ comparing to the $A_{CP}(B_s^0 \to \pi^+K^-) = 0.27 \pm 0.08 \pm 0.02$ [17] which is consistent with U-spin symmetry assumption. LHCb's result shows $A_{\pi\pi}^{\rm mix} = -0.56 \pm 0.17 \pm 0.03$. The significance of nonzero is 3.2σ which is the first evidence of time dependent CP-violation at a hadron collider.

The uncertainties on the LHCb measurements of $A_{\pi\pi}^{\rm dir}$ and $A_{\pi\pi}^{\rm mix}$ are still too large to resolve the discrepancy between the measurements of BABAR [18] and Belle [19], although BaBar is slightly favored.

LHCb performed the first measurement of CP-violation in $B_s^0 \to K^+K^-$: $A_{K^+K^-}^{\rm dir} = 0.02 \pm 0.18 \pm 0.04$ comparing to $A_{CP}(B^0 \to K^+\pi^-) = -0.088 \pm 0.011 \pm 0.008$ and $A_{K^+K^-}^{\rm mix} = 0.17 \pm 0.18 \pm 0.05$ which are consistent with the SM predictions under the U-spin symmetry assumption.

$B_s^0 \to \pi^+\pi^-$ is first observed with 5.3σ significance by LHCb based on 0.37 fb^{-1} data which is shown in Figure 7(b) [20]. The signal yield is 49^{+11}_{-9} and the branching ratio is $(0.95^{+0.21}_{-0.17} \pm 0.13) \times 10^{-6}$. A yield of 13^{+6}_{-5} $B^0 \to K^+K^-$ events is observed too (Figure 7(a)) and the branching ratio is $(0.11^{+0.05}_{-0.04} \pm 0.06) \times 10^{-6}$.

4. $B_s^0 \to \phi\phi$

The $B_s^0 \to \phi\phi$ decay is a pseudoscalar to vector-vector transition. Thus there are only three possible helicity states with amplitudes H_{+1}, H_{-1} and H_0 which can be redefined as

$$A_0 = H_0, A_\perp = \frac{H_{+1} - H_{-1}}{\sqrt{2}}, A_\parallel = \frac{H_{+1} + H_{-1}}{\sqrt{2}}$$

For the V-A structure of the weak interaction, the longitudinal component, $f_L = |A_0|^2/(|A_0|^2 + |A_\perp|^2 + |A_\parallel|^2)$, is expected to be dominant. However, roughly equal longitudinal and transverse components are observed in

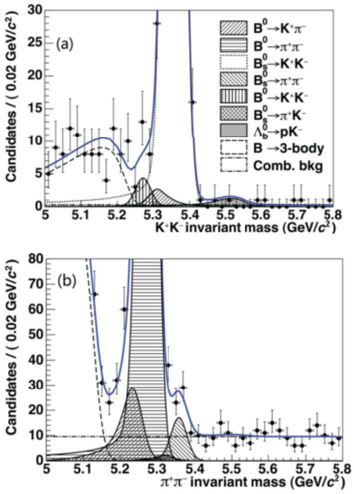

Figure 7: Invariant mass spectra corresponding to the mass hypotheses (a) K^+K^- (b) $\pi^+\pi^-$ [20]

B-factories. And recent LHCb's result in $B_s^0 \to K^{*0}\bar{K}^{*0}$ shows $f_L = 0.31 \pm 0.12 \pm 0.04$ [21]. Various explanations have been proposed: large contribution from penguin annihilation, final states interaction or New Physics [22, 23].

The full angular distribution in $B_s^0 \to \phi\phi, \phi \to K^+K^-$ can be written as

$$\frac{d^3\Gamma}{d\vec{\omega}} \propto \tau_L(|A_0|^2 f_1(\vec{\omega}) + |A_\parallel|^2 f_2(\vec{\omega}) + |A_0||A_\parallel| \cos\delta_\parallel f_5(\vec{\omega})) + \tau_H |A_\perp|^2 f_3(\vec{\omega}) \quad (6)$$

Here $d\vec{\omega} = d\Phi d(\cos\theta_1)d(\cos\theta_2)$ where Φ is the angle between the two ϕ decay planes and $\theta_{1,2}$ are the polar angles of K^+ in the $\phi_{1,2}$ mesons rest frames. $\delta_\parallel = \arg(A_\parallel/A_0)$ is the strong phase difference.

The dataset in the analysis consists of 801 ± 29 candidates collected in 1.0 fb^{-1} events by LHCb in 2011 [24]. By preforming an unbinned maximum likelihood fit, the polarization amplitudes ($|A_0|^2, |A_\perp|^2, |A_\parallel|^2$) are determined to be

$$|A_0|^2 = 0.365 \pm 0.022 \pm 0.012 \quad (7)$$
$$|A_\perp|^2 = 0.344 \pm 0.024 \pm 0.014 \quad (8)$$
$$|A_\parallel|^2 = 0.291 \pm 0.024 \pm 0.010 \quad (9)$$
$$\cos\delta_\parallel = 0.844 \pm 0.068 \pm 0.029 \quad (10)$$

The results are consistent with values from $B_s^0 \to K^{*0}\bar{K}^{*0}$ and also agree well with the CDF measurements [25]. The results favor QCD factorization prediction [26, 27] but disfavor the pQCD expectation [28].

In addition, one can define two triple products

$$U = \frac{\sin 2\Phi}{2}, V = \begin{cases} +\sin\Phi, & \cos\theta_1\cos\theta_2 \geq 0 \\ -\sin\Phi, & \cos\theta_1\cos\theta_2 < 0 \end{cases}$$

to investigate the *CP* symmetries

$$A_{U(V)} = \frac{\Gamma(U(V) > 0) - \Gamma(U(V) < 0)}{\Gamma(U(V) > 0) + \Gamma(U(V) < 0)}. \quad (11)$$

$A_{U(V)}$ is zero in the SM. Therefore a significant asymmetry is signal of New Physics.

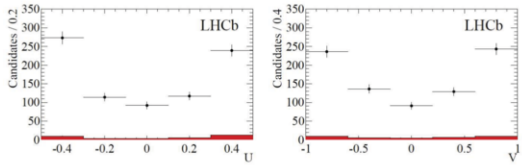

Figure 8: Distributions of the U (left) and V (right) observables [24]

The distributions of U and V are shown in Figure 8. The measured values are $A_U = -0.055 \pm 0.036 \pm 0.018, A_V = 0.010 \pm 0.036 \pm 0.018$. Both values are in good agreement with the CDF's results [25] and also consistent with *CP* conservation hypothesis.

5. $B_s^0 \to KK$

In the SM, the proper time distribution of $B_s^0 \to KK$ can be parameterized as [29]

$$\Gamma(t) = (1 - A_{\Delta\gamma_s})e^{-\Gamma_L t} + (1 + A_{\Delta\gamma_s})e^{-\Gamma_H t} \quad (12)$$

where Γ_H, Γ_L are the decay widths of the heavy and light B_s^0 mass eigenstates and $\Delta\Gamma_s = \Gamma_L - \Gamma_H$ is the decay width difference. $A_{\Delta\Gamma_s}$ is the decay rate asymmetry.

Fitting the distribution above with a single exponential function will give the effective lifetime

$$\tau_{KK} = \tau_{B_s^0} \cdot \left(1 + A_{\Delta\Gamma_s}\frac{\Gamma_L - \Gamma_H}{\Gamma_L + \Gamma_H}\right). \quad (13)$$

In the SM $A_{\Delta\Gamma_s}$ is close to 1 and the effective lifetime τ_{KK} is predicted to be 1.40 ± 0.02 ps [8]. However, deviation may be introduced by new physics.

In the analysis [29], 1024 ± 39 $B_s^0 \to KK$ candidates are obtained. Unlike the traditional measurement of B meson lifetime, a minimal bias selection is adopted in the analysis. The technique is based on neural networks which avoids acceptance effects and no selections on lifetime biased variables.

The effective lifetime is evaluated using unbinned log-likelihood fit to be $\tau_{KK} = 1.455 \pm 0.046 \pm 0.006$ ps. The value is in good agreement with the SM prediction and LHCb's result $\tau_{KK} = 1.440 \pm 0.096(\text{stat}) \pm 0.008(\text{syst}) \pm 0.003(\text{model})$ ps based on 37 pb^{-1} pp data collected in 2010 [30].

6. Conclusion

2011 has been an excellent year for LHCb : about 1 fb^{-1} pp collision data has been collected. This large amount of data has allowed to obtain world best measurements or first observations in hadronic B decays. In 2012, more than 1 fb^{-1} of data has already been recorded at an energy of 8 TeV in the center of mass frame and 1.5 to 2 fb^{-1} can be reasonably expected.

References

[1] A. A. Alves *et al.* [LHCb Collab.], JINST, **3**, S08005, 2008
[2] B. Adeva *et al.* [LHCb Collab.], hep-ex/0912.4179
[3] M. Gronau and J. L. Rosner, Phys. Rev. D **87**, 096013 (2011)
[4] W. Bensalem and D. London, Phys. Rev. D **64**, 116003 (2001)
[5] A. Datta and D. London, Int. J. Mod. Phys. A **19**, 2505 (2004)
[6] Y. Grossman, Phys. Lett. B **380**, 99 (1996)
[7] A. Lenz and U. Nierste, JHEP **06**, 72 (2007)
[8] R. Fleicher and R. Knegjens, Eur. Phys. J. C **71**, 1532 (2011)
[9] R. Fleicher, Eur. Phys. J. C **52**, 267 (2007)
[10] M. Gronau and D. London, Phys. Lett. B **253** 483 (1991)
[11] M. Gronau and D. Wyler, Phys. Lett. B **265** 172 (1991)
[12] D. Atwood, I. Dunietz and A. Soni, Phys. Rev. Lett **78** 3257 (1997)
[13] I. Dunietz and A. Soni, Phys. Rev. D **63** 036005 (2001)
[14] R. Aaij *et al.* [LHCb Collab.], LHCb-PAPER-2011-001, arXiv:1203.3662
[15] Y. Amhis *et al.* [HFAG Group], arXiv:1207.1158
[16] R. Aaij *et al.* [LHCb Collab.], LHCb-CONF-2012-007
[17] R. Aaij *et al.* [LHCb Collab.], Phys. Rev. Lett. **108** 201601 (2012)
[18] B. Aubert *et al.* [BaBar Collab.], arXiv:0807.4226
[19] H. Ishino *et al.* [Belle Collab.], arXiv:hep-ex/0608035
[20] R. Aaij *et al.* [LHCb Collab.], LHCb-PAPER-2011-002, arXiv:1206.2794
[21] R. Aaij *et al.* [LHCb Collab.], Phys. Lett. B **709** 50 (2012), arXiv:1111.4183
[22] A. L. Kagan, Phys. Lett. B **601** 151 (2004), arXiv:hep-ph/0405134
[23] A. Datta *et al.*, Phys. Rev. D **76** 034015 (2007), arXiv:0705.3915
[24] R. Aaij *et al.* [LHCb Collab.], LHCb-PAPER-2011-004, arXiv:1204.2813
[25] T. Aaltonen *et al.* [CDF Collab.], Phys. Rev. Lett. **107** 261802 (2011), arXiv:1107.4999
[26] M. Beneke, J. Rohrer and D. Yang, Nucl. Phys. B **774** 64 (2007)
[27] H. Y. Cheng and D. K. Chua, Phys. Rev. D **80** 114026 (2009)
[28] A. Ali, Phys. Rev. D **76** 074018 (2007)
[29] R. Aaij *et al.* [LHCb Collab.], LHCb-PAPER-2012-013, arXiv:1207.5993
[30] R. Aaij *et al.* [LHCb Collab.], Phys. Lett. B **707** 349 (2012)